

***OPTIMIZATION OF ENVIROMENTAL CONTROL TO FIT LIVING  
SPACE REQUIREMENTS***

A Senior Thesis

By

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# Optimization of Environmental Control to Fit Living Space Requirements

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# **Optimization of Environmental Control to Fit Living Space Requirements**

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## **ABSTRACT**

This study examines the application of Environmental Control Systems (ECSs) for people with disabilities who live in the dormitory. ECSs allow people with disabilities to control appliances in their homes and parameters in their environment. The purpose of this study is to analyze effectiveness and efficiency of current ECSs when they are used in this setting, and formulate ways of reducing the cost and complexity of these systems. ECSs are compared against the needs of a real client with disabilities who lives in a dormitory room on the Texas A&M University main campus. General conclusions about the strengths and weaknesses of the systems, when applied to the small living space, are formulated. Alternative ECS designs are conceived and discussed. Finally, an example ECS component subsystem design is produced in detail.

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## Summary

The purpose of this study is to find ways of developing low cost environmental control systems (ECSs) intended for use in dormitory rooms by people with disabilities. ECSs allow users to gain improved access to the appliances and environment within their home. The systems must be able to accept many forms of input from devices such as sip/puff switches or push-buttons and translate this input into many different forms of output.

This study first examines the hypothetical application of commercially available ECSs for people with disabilities who live in the dormitory. Most ECSs are not optimized for the dormitory room environment; they have inappropriate functions which can be wasted. This waste reduces the cost effectiveness of the systems. Reduction of ECS cost and optimization of environmental control in small living spaces (like the dormitory) would make ECSs more available to students living in those environments. Currently, the price of a fully functional ECS can range from \$1000-\$6000.

An actual client, Mr. Russel Rawlings, is interviewed to see what he considers are the most important functions of environmental control in his dormitory room. His needs, abilities, and environment are compared against 14 ECSs which were discovered from advertisements. The ECSs are evaluated and rated.

Aside from wasted functions, some ECSs also demonstrate other weaknesses. Mobility and control over temperature are not well addressed in some cases. Over-centralization also makes ECSs more expensive because of the relative difficulty of packaging full functionality in one central control device rather than many control devices.

Two alternative design concepts are presented. They are the DSP based X10 Controller and the Infrared Point and Click subsystems. These designs are used to employ segmentation of the user input and control mechanisms in a comprehensive ECS. The cost of the systems become significantly lower than that of most ECSs.

The design of the Infrared Point and Click environmental control subsystem, intended for integration into a complete system, is given in detail. Its components were physically built and laboratory tested. Although one of the original goals of this study was to have a real client evaluate the ECS, Mr. Rawlings did not return for the Spring Semester, and therefore the subsystem remains untested in the field.

## Introduction

The adaptation of home automation to people with disabilities has greatly improved the accessibility of the home environment. The modern Environmental Control System (ECS) has become very sophisticated, and is able provide a large range of environmental controls and a large amount of flexibility for users.

The many devices that a modern ECSs control can be classified into a few groups. There are appliances which respond to infrared transmission of codes--televisions, VCRs, stereos, etc. There are X-10 units, which themselves control lights, power to appliances, power to wall sockets, temperature, and countless other aspects of the environment. There are specialized devices such as powered door openers, page turners, and telephones. Finally, there is the personal computer. A typical ECS can allow a disabled user to control hundreds of devices.

The methods of extending control to the user can also be sophisticated. Not only can most ECSs interface with a simple switch such as a sip/puff or a head switch, but some can also respond to voice input. User profiles and timed macros of events can be programmed and stored. If the user's physical abilities decline or improve, then the ECS can be adjusted to meet those needs.

The current ECS appears to have the capability to adapt to any situation and almost any user. Almost complete control over appliances and aids can be achieved. It is likely that in a house there is the potential to approach full usage of all of the available functions. However, the full functionality would not realistically be achieved in a small, one room environment such as the college dormitory room.

Most environmental control systems "go for the gold," by incorporating as many control options and supported user input modalities as possible. Unfortunately, most ECSs cost more than \$3000, and there are not many scaled down alternatives which are more cost effective for a small environment. This high cost may make environmental control out of reach for most students. The problem of the high cost is compounded by funding limitations. ECSs are usually not considered to be medical or educational necessities, and therefore are not funded by the government or private insurance companies.

The purpose of this study is to first develop evaluations of the effectiveness and efficiency of existing ECSs that are hypothetically applied to a real client's needs in a dormitory room. The conclusions about strengths and weaknesses in the current designs are then used to formulate two possible alternative ECSs which are allowed to break the traditional molds. Finally, the design of one alternative system is presented in detail.



## **Part I:**

# **Examination of Environmental Control in the Dormitory**

There is a potential market for ECSs which efficiently meet the needs of a people in small, communal living spaces. In almost every college dormitory there are people with disabilities. This section compares several ECSs to the stated needs and abilities of an actual student with disabilities. In doing so, ECS functions that are wasted (not used), or are lacking, are identified. Methods of control may be inappropriate, and these cases are identified. Based on the analysis, recommendations are made for alteration of ECS design.

## **Environmental Requirements**

Before available ECSs are analyzed, the requirements of the selected client and the aspects of the dormitory room environment must be presented. These parameters will provide a framework for evaluating the ECSs in a logical fashion. Our client's abilities, needs, and dormitory room will be examined in detail.

### **THE CLIENT**

Russel Rawlings, an undergraduate student at Texas A&M University, volunteered to take part in this study. He lives in a modular dormitory room; there is one bathroom and one roommate. Figure 1 is a photograph of Mr. Rawlings in his dormitory room.

**Mr. Rawlings**



**Figure 1:** Mr. Rawlings, and roommate in background.

## **MR. RAWLINGS' ABILITIES**

Mr. Rawlings is nearly quadriplegic, and has limited control over his arms and upper torso. He has limited dexterity which is mostly present in his right hand. Significant bone structure is present primarily in the index finger of both hands. He has full verbal communication abilities and full sensation.

Mr. Rawlings' primary mode of transportation is his powered wheelchair. A joystick mount with an elbow cup interfaces with his right elbow. A tray supports his arms. On the tray, in the upper right corner, are two, single button garage door openers. One opener sends the code which will open his powered room door, and the other opener activates a powered door at the main entrance of the dormitory.

The amount of dexterity that Mr. Rawlings has allows him to manipulate buttons the size of computer keyboard keys or larger. Given time, Russel can type on his computer. He can also use the two garage door remote controls which trigger the powered doors.

Mr. Rawlings requires assistance to perform many physical tasks such as dressing, bathing, eating, and obtaining objects. For activities pertaining to personal hygiene and dressing, a personal attendant aids Mr. Rawlings. His friends and roommate assist with the other activities as they arise in a social setting.

## **MR. RAWLINGS' NEEDS**

In personal interviews with Mr. Rawlings, he identified the aspects of his living space that he would like to have improved control over. At the top of the list are control over the temperature of the room, lights, wall outlets, and the door to the room. Telephone access, control over the TV, VCR, or stereo are next, and control over the blinds are least important. Table 1 shows this hierarchy and related factors in the dormitory setting.

### Mr. Rawlings' Requirements

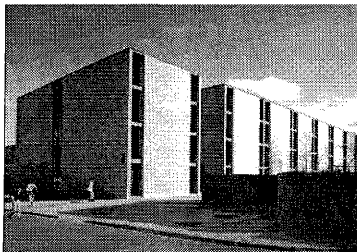
| Functions              | Quantity   | Special Requests   | Special Considerations  |
|------------------------|------------|--|---|
| Thermostat & Blower    | 1          | Control of this function is very important.  | The fan blower is usually left at one setting. Control over the thermostat is the main problem.   |
| Light Switches         | 4          |  | Two of the four light switches in the room are connected to fluorescent lights. Environmental control devices designed to replace fluorescent light switches are more expensive.  |
| Wall Outlets           | 2 (of 6)   |  | The most useful appliance On/Off functions would be for auxiliary lamps, alarm clocks with battery backup, and the computer.<br><br>Two outlets in the bathroom would probably not be used. Two outlets in the living room would be used by the roommate. |
| Automatic Door Openers | 2          | Wishes to consolidate the two garage door remote controls down to one.                       | Alteration of the main entrance door opener will not be possible (impacts other residents).   |
| Television VCR Stereo  | 3 (1 each) | Needs improvement over regular remote controls. They can be used, but with difficulty.       | It is not necessary that there is continual access to these appliances, i.e. a separate control subsystem would be satisfactory   |
| Telephone              | 1          | Needs a way to remotely answer the phone more quickly. Preprogrammed dialing also important. | Many products (ECs or separate phone control systems) provide sophisticated "hands-off" phone control.  |
| Blinds                 | 1          |  | Products exist which are specialized toward this single function.   |

**Table 1:** Environmental control functions requested by Mr. Rawlings. The more important functions are towards the top of the list.

### MR. RAWLINGS' ENVIRONMENT

Mr. Rawlings lives in the Les Appelt Dormitory at Texas A&M University. This dormitory is the modular style: there are two roommates and a single bathroom. Figure 2 shows an exterior view of Les Appelt Dormitory. The gap in the building is the one of the two entrances. This particular entrance has a powered door which responds to garage door openers sending the correct code. Mr. Rawlings uses this entrance.

## Les Appelt Dormitory at Texas A&M University

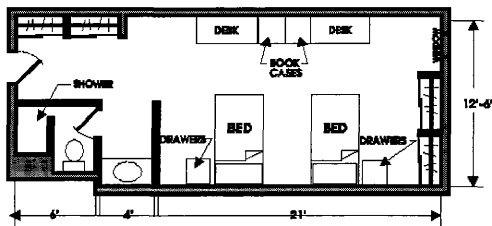


**Figure 2:** Outside of Les Appelt Dormitory, Texas A&M University.

Source: "Modular Halls." Feb. 1998. <<http://housing.tamu.edu/housing/graphics/appe.jpg>> (March 1998).

Figure 3 depicts the layout of the dormitory room. Mr. Rawlings' desk and bed are closer to the entrance. His stereo equipment is located between the first desk and the entrance. The television and VCR lie on the book cases.

### Modular Dormitory Room



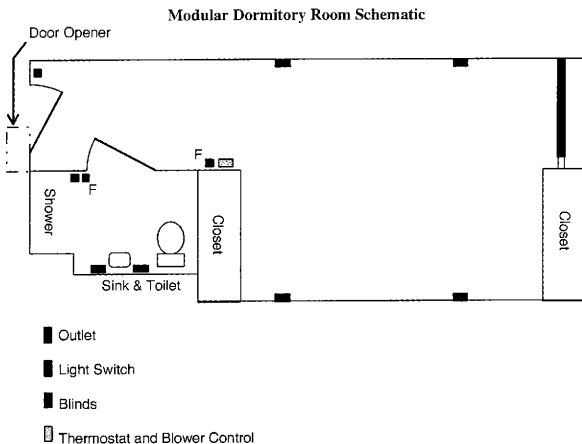
**Figure 3:** Layout and dimensions of the typical modular dormitory room style at Texas A&M University.

Source: "Modular Halls." Feb. 1998. <<http://housing.tamu.edu/housing/styles/modular.htm#floorplan>> (March 1998).

The overall dimensions of the room are 31' by 12' 6". There are some differences between this depiction of the room layout and the actual layout of rooms altered for improved handicap accessibility. The closet nearest the entrance is adjacent to the bathroom. This

widens the entrance for residents with wheelchairs. Mr. Rawlings' bed is also turned lengthwise and placed flush against the long wall.

Other features of the room need to be examined. These are the location of the thermostat, fan blower control, light switches, and wall outlets, and blinds. Figure 4 is schematic representation of the dormitory room (not necessarily to scale). There are six outlets, four light switches, a set of blinds, a thermostat, and a blower control switch with four settings (off, low, medium, and high). Of the four light switches, two of them (labeled "F") are for fluorescent lighting.



**Figure 4:** Schematic of Mr. Rawlings' handicap accessible room. Outlets, light switches, blinds, the thermostat, and the blower control are shown. The fluorescent light switches are labeled "F."

The fluorescent light switches are labeled because they have specific implications when it comes to control. The X10 components that can replace these wall switches are significantly more expensive than conventional wall switch receivers. Refer to Appendix A for examples of X10 modules and the method of communication that they use.

## Analysis of Available Environmental Control Systems

A non-biased list of commercially available environmental control systems has been compiled. These systems were automatically selected for this study upon discovery. The primary source of information on the systems comes from Internet advertisements. Other information comes from a home automation catalog.

Fourteen environmental control systems or significant subsystems were identified. These systems' characteristics are compared against Mr. Rawlings' needs, abilities, and environment. There are undoubtedly more systems that haven't been included, but the search was terminated for the sake of brevity.

### SUMMARY OF SYSTEMS

In this section, a brief summary of each system is given. Afterward, the systems and the devices that they can control are tabulated and analyzed.

| System Name   | Manufacturer         |
|---|----------------------|
| DEUCE   | ATP Technology, Inc. |
| DEUCE is a switch controlled ECS. Feedback consists of a visual display and audio tones. Dual switches (sip/puff, tongue/lip, 2 body switches) can be used. Some appliances can be controlled by direct connection to the base unit, which has 4 AC outlets. Additional X10 control may be added as an option.<br>(Rehab Designs, Inc., 1996)           |                      |
| FreeSwitch™   | Adaptivation         |
| The FreeSwitch™ system controls only X10 units. It's defining feature is that it uses customizable "Taction" (tactile action) pads which the user touches to turn on (or off) the desired device. The pads interface with 4 channel X10 transmitters, which then control other X10 units.<br>(Adaptivation)   |                      |
| GEWA and the INFRA-LINK System  | ZYGO Industries      |
| The GEWA programmable infrared transmitter is a portable unit which the user manipulates to activate remote infrared receivers. The receivers comprise the INFRA-LINK system, a group of strategically placed receivers that have some processing function (Woodlake Technologies, Inc., 1998). These receivers control the devices in the environment. |                      |

Input may be accomplished either with the transmitter button pad or with a dual state ability switch such as a sip and puff switch. There is no advanced feedback, but the user is aware of the selection by visual recognition of the activated device.  
(ZYGO Industries)

HECS (Hospital Environmental Control System)      Prentke Romich

HECS has special features which allow control over such things as a nurse call and hospital bed. Dual state ability switches are used to control the unit.  
(Rehab Designs, Inc., 1996)

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Imperium®200H

Teledyne Brown Engineering

The Imperium®200H is an environmental control system which is controlled by an ability switch. Feedback is voice output and a visual display. An RF transmitter can be used for input if mobile access (e.g. on a wheelchair) is desired.  
(Teledyne Brown Engineering)

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PROXi

Madanta Communications, Inc.

PROXi is an environmental control system that uses an existing personal computer as the centralized control device. The PROXi unit communicates through a Macintosh or IBM compatible computer over the serial port. Other supported CPUs are Ke:nx™, Liberator™, Intellikeys™, Dynavox™, and Apple Newton®.

Voice input or a wireless transceiver provide input to the system. Dragon Dictate software drives the voice recognition aspect of the system, and the PROXi software provides the hardware control. Feedback is seen on the computer screen in the form of icons which represent actual devices and events activated by the user.  
(Madanta Communications, Inc., 1997)

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Scanning Director™  
Director™

Prentke Romich

The Scanning Director™ is an environmental control sub-system which is used in many other complete systems. It is a programmable IR transmitter which can control several appliances that rely on IR control, such as televisions and VCRs. New codes are learned and devices can be added or subtracted from a list. Input is a single or dual state switch. The Scanning Director™ also has an X10 control option which uses an X10 IR transceiver to send on/off commands to X10 modules.

The Director™ is similar, but uses ASCII or RS232 input (e.g. from a computer) and has no X10 option.  
(Rehab Designs, Inc., 1996)

### Simplicity™ Series 5,6

Quartet Technology, Inc.

The Simplicity™ Series 5 and 6 respond to voice input. The user issues vocal commands to scroll through menu systems to activate the desired appliances or devices. For example, the user may say "TV" and then issue another command "Turn On."

These systems provide feedback on what functions the user is activating through human sounding voice output. Series 6 differs from 5 in that it allows the user to control an IBM compatible personal computer.  
(Rehab Designs, Inc., 1997)

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### Simplicity™ Series 7,7M

Quartet Technology, Inc.

These environmental control systems are almost identical to the Simplicity™ Series 5 and 6 with the exception that inputs from switches are used rather than voice input. Series 7 is the analog of Series 5, while Series 7M is the analog of Series 6.  
(Rehab Designs, Inc., 1997)

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### Simplicity™ Series Four-In-One

Quartet Technology, Inc.

The Four-In-One line combines functions of the previous Series 5, 6, 7, and 7M. Both voice feedback and an ability switch input may be used. Computer control is also supported. Other features are very similar to the previous models.  
(Rehab Designs, Inc., 1996)

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### X10 Activehome Computer Interface Kit

X10

This system uses the personal computer for control. The X10 CM11A module allows the computer to communicate with X10 receivers either directly over the home power wiring or through an X10 radio frequency transceiver. The user interface is windowed and allows the user to select and control devices with the mouse.  
(Home Automation Systems, Inc., 1998)

## BREAKDOWN OF SYSTEMS

Currently available environmental control systems tend to support a large number of control options. Almost all of the systems lend the user the ability to activate lighting and operate entertainment appliances which use infrared remote controls (e.g. television). Integrated telephones, complete with phone number memory, re-dial, speakerphone, call waiting flash, etc., are also very popular. Some systems can control assistive equipment such as electric hospital beds and page turners. A few systems additionally allow the user to operate a personal computer.

Among the very complete systems are the Simplicity™, DEUCE, Imperium®200H, PROXi, HECS, GEWA, and the X10 Activehome Computer Interface Kit. It should be



noted that many of the functions that these systems support are not included in the base system--optional hardware must be purchased to gain full functionality.

A few other systems are very specific in the range of devices that they control. These systems are the Director<sup>TM</sup>, Scanning Director<sup>TM</sup>, and FreeSwitch<sup>TM</sup> systems. The first two control infrared devices, while the last controls only X10 lamp and appliance modules.

### **Synthesis of Characteristics**

Tables 2a and 2b tabulate the available control options of the selected ECSs. Functions are considered to be supported if the manufacturer specifically claims that those functions are available. Each relevant function that Mr. Rawlings described is included with the exception of thermostat control. Thermostat control was not specifically mentioned in any advertisement as a supported function. The groups for lighting and wall outlet control are combined under the "L,A" column, since the control methods are essentially the same.

The cost reported is the retail price of the device as stated on advertisements or by customer support agents. The cost does not include optional peripherals. Most systems require some additional X10 equipment or another whole subsystem such as a voice activated telephone.

While no systems natively support temperature control, and many do not support blinds control, there are X10 compatible products which can compensate for these shortcomings. X10 thermostat modules can be used to trick or replace existing thermostats. Also, there are powered blinds controllers which respond to simple X10 commands. Further elaboration on these options can be found in the Evaluations Summary section. For the sake of clarity, these X10 expansions are not considered in Table 2a and 2b.

## Environmental Control System Synthesis

| System                       | Input                         | Feedback        | L,A             | IR     | Door | Blinds | Hands-off Telephone | Other Devices Controlled   | Cost (\$)    |
|------------------------------|-------------------------------|-----------------|-----------------|--------|------|--------|---------------------|--|--------------|
| DEUCE                        | Dual switch, Wireless switch  | Display or Tone | 4               | 2      | Yes  | Yes    | Yes                 | Remote display<br>Call signal<br>Tape recorder<br>16 X10 L or A modules maximum<br>Powered Bed<br>Personal Computer      | 1675         |
| Director™                    | ASCII, RS232                  | None            | 0               | N.S.   | No   | No     | No                  | None stated  | 495          |
| Free-Switch™                 | Tactile pads                  | None            | 4 X10           | No     | No   | No     | No                  | 64 X10 maximum, needs 16 transceivers  | 255          |
| GEWA                         | Buttons, Single switch        | None stated     | N.S.            | N.S.   | Yes  | Yes    | Yes                 | Personal Computer<br>Elevator<br>Alarm<br>Powered bed<br>Page turner   | 895          |
| HECS                         | Dual switch                   | LCD Display     | 2               | 1 (TV) | No   | No     | Yes                 | Powered Bed<br>Nurse Call  | 3860         |
| Imperium®200H                | Switch, Wireless switch       | Voice, Display  | 1L<br>3A<br>X10 | 6      | No   | No     | Yes                 | Powered Bed<br>Tape recorder<br>16 X10 L or A modules maximum<br>Nurse Call  | 3380         |
| PROXi                        | Voice recog., Wireless switch | Computer screen | 256 X10         | 8      | No   | No     | Yes                 | Powered bed<br>Intercom  | 2495         |
| Scanning Director™           | Single, Dual switch           | LCD display     | N.S.<br>X10     | N.S.   | No   | No     | No                  | None stated  | 785          |
| Simplicity™ Series 5, SS1058 | Voice                         | Voice           | 1L<br>1A<br>X10 | 6      | Yes  | No     | Yes                 | Powered Bed<br>Page turner<br>Nurse call<br>X10 16 L * 16 A modules maximum<br>Medical equipment (UL and CSA recognized) | 4285<br>4950 |

**Table 2a:** This table examines the input, feedback, controlled devices, and cost of the chosen environmental control systems. The first ten are shown in alphabetical order. Gray boxes indicate that the proposed device/function is available, but only as an option.

Key: #L # of lamp control modules, which can dim or toggle a lamp that it powers.

#A # of appliance control modules, similar to lamp module, but rated for higher power.

L,A Devices which are typically controlled by variably supplying power, such as lights.

IR Devices which are controlled by infrared remote controls, esp. TV, VCR, and Stereo.

N.S. The limit of controllable devices of the given type not specified.

### Environmental Control System Synthesis (continued)

| System                                 | Input                 | Feedback        | L,A             | IR | Door | Blinds | Hands-off Telephone | Other Devices Controlled  | Cost (\$) |
|--|-----------------------|-----------------|-----------------|----|------|--------|---------------------|---|-----------|
| Simplicity™ Series 7,<br>IBM PC        | Dual switch           | Voice           | 1L<br>1A<br>X10 | 6  | Yes  | No     | Yes                 | Powered Bed<br>Page turner<br>Nurse call<br>X10 16 L + 16 A<br>modules maximum<br>IBM PC<br>Medical equipment<br>(UL and CSA<br>recognized) | 4365      |
| Simplicity™ Series Four-In-One         | Dual switch,<br>Voice | Voice           | 1L<br>1A<br>X10 | 6  | Yes  | No     | Yes                 | Powered Bed<br>Page turner<br>Nurse call<br>X10 16 L + 16 A<br>modules maximum<br>IBM PC<br>Medical equipment<br>(UL and CSA<br>recognized) | 5750      |
| X10 Active-home Computer Interface Kit | Computer              | Computer screen | 1L<br>X10       | 6  | No   | No     | No                  | 256 X10 devices maximum   | 89        |

**Table 2b:** The last four systems.

- Key:   #L       # of lamp control modules, which can dim or toggle a lamp that it powers.
- #A       # of appliance control modules, similar to lamp module, but rated for higher power.
- L,A      Devices which are typically controlled by variably supplying power, such as lights.
- IR       Devices which are controlled by infrared remote controls, esp. TV, VCR, and Stereo.

### System Evaluations

Each system is now given a short evaluation. Factors that are considered are the availability of the desired functions, the feasibility of using the system in Mr. Rawlings' environment, and the cost of the system.

DEUCE

ATP Technology, Inc.

This system can potentially fulfill all of Mr. Rawlings' needs with purchase of the appropriate options. The IR remote control, door control, and blinds control options must be obtained. A large button can be used as the switch input; this is within his control capability.

Assuming that Mr. Rawlings uses two of the four outlets in the main room for his own lamps, alarm clock, computer, etc., he needs control over four jacks. The DEUCE can provide this control without the purchase of more X10 modules and an X10 interface for the system. However, four X10 light switches would need to be purchased.

A remote transmitter would be desirable for Mr. Rawlings, since he remains mobile in his wheelchair. A problem arises with the display; there may be instances when he will want to activate a device in his room that he is looking at, but not be able to see what he has selected in the display. He would have to rely on the tone information which might not be as easy to adapt to.

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#### FreeSwitch™

#### Adaptivation

This system is unique both because of its method of input and its very narrow range of controlled items. This system can only control X10 units that perform on/off functions. X10 modules of this nature can handle the lighting, wall outlet, blinds, and temperature (with a temperature setback controller) controls. The other control functions apparently are not achieved with this system.

The nature of the control might pose a problem for Mr. Rawlings, since he cannot easily reach objects beyond his tray. However, if his roommate or attendant were available to place the pads on his tray then he could use the system.

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#### GEWA and the INFRA-LINK System

#### ZYGO Industries

A defining feature of this system is that it spreads out the higher functions of controlling appliances. A portable, programmable IR transmitter interprets the user input either through an on-board keypad or plug-in ability switch. This transmitter directly controls appliances such as televisions and VCRs, but also communicates with INFRA-LINK receivers. Some of the INFRA-LINK receivers are simple light sockets and wall sockets which then control the user's on/off type appliances. Others, like the INFRA-LINK telephone, are more complicated.

This system offers control over almost every function. No X10 units are used; instead, the INFRA-LINK devices are unique and built around the GEWA programmable transmitter. This method of control might work well with Mr. Rawlings; the transmitter is small, responds to switch or on-pad buttons, and is portable. Directional selection with the remote control or menu scanning of devices is possible with the GEWA system. Mr. Rawlings would not need an assistant to continually add or remove the controller from his tray.

Since the proprietary receivers must have the ability to respond to IR codes, they tend to be very expensive. For comparison, if the system were purchased with 8 wall outlet or light switch receivers (\$330, \$310 respectively) and a GEWA compatible telephone

(\$695), the added cost would be \$3255 to the transmitter which costs \$895. This pushes the price of the GEWA system near some of the most expensive ECSs.

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HECS (Hospital Environmental Control System)      Prentke Romich

HECS, which is designed around the hospital environment, is not well suited to Mr. Rawlings' requirements. Only 2 AC devices are supported, the display is fixed, only one TV can be controlled. Door and blinds control are not supported. Also, the functions of bed control and nurse call are not necessary. The cost of the system falls in the middle to upper range of the selected systems.

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Imperium®200H

Teledyne Brown Engineering

The base Imperium®200H unit allows control over 4 X10 modules (with many more optional), 6 IR appliances, and the telephone. However, door control does not appear to be supported.

Some features of the system which would benefit Mr. Rawlings' are the wireless transmitter and the voice feedback. Both features are compatible with his wheelchair mobility. This system falls in the middle range of prices.

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PROXi

Madenta Communications, Inc.

PROXi, which has telephone control and the options to control up to 256 X10 devices and 8 IR appliances, does not support door control or blinds control (unless X10 is used). A personal computer serves as the central control mechanism, and many brands of computers are supported.

While PROXi suffers from having a non-portable computer screen for feedback, it offers a wireless microphone transmitter and voice recognition software. Control would be easy, and this system partially allows wheelchair mobility.

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Scanning Director™  
Director™

Prentke Romich

Although the Director™ was identified as a pertinent environmental control subsystem, it would not be a feasible choice for Mr. Rawlings because it uses computer input over a serial connection. (The Director™ is sometimes used as a component in other environmental control systems.) This subsystem would need to be used in conjunction with some CPU.

However, the Scanning Director™ might be useful, since it responds to ability switches, controls IR devices, and has an X10 option. Only telephone and door control would not be covered by this system with the appropriate X10 modules. The switch would have to

be placed on the tray by an assistant when in use. The cost is on the low end in the list of systems.

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#### Simplicity Series 5, 6, 7, 7M, Four-In-One

Quartet Technology, Inc

These systems are very complete, with some using switch input and some using voice input. Some offer PC control and some do not. All offer voice feedback. The voice control models, in conjunction with optional remote microphones, promote full mobility.

While the base units do not come with enough X10 units (only 2) many more can be controlled. Only the blinds and temperature functions are not natively supported, but these can be controlled with the X10 devices.

These systems meet all of Mr. Rawlings' control requirements, along with many others that are unnecessary. Their only drawback is that they have the highest prices of any of the systems.

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#### X10 Activehome Computer Interface Kit

X10

While the base system is amazingly inexpensive, it suffers from some drawbacks. Telephone and door control are not supported, and the computer interface is not tailored to someone with motile disabilities. Also, the computer is not a portable control mechanism. This system might be more useful in conjunction with a special mouse or a joystick.

### EVALUATIONS SUMMARY

Here, overall evaluations of the systems are given. Trends, strengths, and weaknesses in the systems are identified for each environmental control function that Mr. Rawlings requested.

#### Temperature Control

Temperature control is the only need which was not identified as a supported function in any of the systems. While there are X10 compatible thermostats which can be told to select any temperature, the systems identified in this study may not be able to support them. However, there is a less sophisticated alternative--the HAS-3000 X10 Powerhouse Thermostat Set-Back Controller (Home Automation Systems, Inc., 1998). This device plugs into a lamp module, mounts underneath the existing thermostat, and has a heating element which produces a false shift in the temperature. This can be used to activate air-conditioning upon turning that lamp module on. In the winter, the device can be left on and the thermostat set down--then the heat can be activated on command.

### **Lights and Wall Outlets.**

Almost all systems that were reviewed had the ability to provide on/off control over light switches, lamps, and other appliances that plug into X10 compatible modules. The exceptions were the Director™, which could not control X10, and the GEWA system, which had its own control modules.

Most systems would require the purchase of more X10 modules, as few modules came standard with the systems. Mr. Rawlings would need 8 modules: 2 regular light switches, 2 fluorescent light switches, and 4 appliance/lamp modules. These would fulfill lighting and wall outlet control options at a cost of about \$150. Additional X10 modules for thermostat setback and blinds control would need to be purchased by the user.

### **Powered Door Opener**

Only three of the system brands, DEUCE, GEWA, and the Simplicity Series models, identified powered door control as an option. Mr. Rawlings' would need a way to access these systems outside the dormitory room and outside the main dormitory entrance.

Unfortunately, it is unlikely that a wireless microphone or switch would be able to reach the base control unit inside of the room from outside the dormitory. Additionally, modification or replacement of the main entrance door opener would impact other residents in the hall.

At best, with the limitation that all commands must pass through a centralized control unit, use of the appropriate ECS would eliminate one of the garage door remote controls from Mr. Rawlings' tray while adding another control item to the tray.

### **TV/VCR/Stereo**

Every system with the exception of the FreeSwitch™ system can control IR appliances. The most common appliances that respond to this method of control are televisions, VCR's, and stereos. The voice or switch input modality of the environmental control systems is an improvement over the conventional remote control, which is difficult for Mr. Rawlings to manipulate.

### **Telephone**

With the exception of the Director™, Scanning Director™, FreeSwitch™, and the X10 Activehome Computer Interface Kit, the environmental control systems come with built in telephones. The integrated telephones are all very similar. Aside from recognizing the processed user input, they support automatic answering, memory speed dialing, and call waiting. Speakerphones eliminate the necessity of manipulating a hand-held phone.

For the systems that do not include phone support, there are products specifically made for that purpose. Examples are the RC100 and RC200 by Assis-TECH, Inc. (Assis-TECH, Inc., 1997). The RC100 costs \$300, and uses an air sensitive switch which can be used to answer the telephone or switch through 6 programmed numbers. The RC200 adds voice control, and 14 more memory banks. It's price tag is \$400. For accuracy in comparisons, these costs should be kept in mind when comparing the costs of base environmental control units.

Currently Mr. Rawlings can use a normal phone that is equipped with a speaker, but with some difficulty. To answer the phone he must carefully maneuver himself close enough to reach the speakerphone button. Mr. Rawlings can dial numbers slowly, and also relies on assistance from his friends, attendant, or roommate to dial numbers.

### **Blinds Control**

Although most systems do not say that they support blinds control, the systems that have X10 and IR capability can control motorized drape and blind mechanisms that are compatible with those form of communication. One such device is the Home Automation Systems Drape Boss, which has both X10 and IR control options (Home Automation Systems, Inc., 1998).

### **Wasted Functions**

Many of the systems in this study have features which were not desired by Mr. Rawlings. These include control over hospital beds, home security systems, timed macros of events, page turners, personal computers, tape recorders, nurse calls, and medical equipment.

Some of these functions are wasted primarily because of Mr. Rawlings' personal preferences. Mr. Rawlings did not consider control over his personal computer, a page turner, or tape recorder as important as some of the more basic functions of lighting, temperature, and door access.

Other features have a high probability of waste in other users due to the environment itself. For example, home security and timed macros of events may complicate the roommate arrangement and the variability of schedules in college life. Also, the use specialized hospital functions such as hospital bed control and nurse calls would also be unlikely. If personal alert pendants were desired, there are products which handle this function without the need for ECS support. Additionally, we have already established the complication of altering or replacing the standard door opener equipment because the main entrance door opener must be used by other people.

Flexibility may increase the marketability of environmental control systems, as it allows for adaptation to users of different abilities. However, the complex functionality which must be integrated in a centralized control device (either a base unit or PC) increases the cost of



the system. Under Mr. Rawlings' conditions, this excess centralized control potential represents unnecessary cost.

The systems which would demonstrate the least waste under Mr. Rawlings requirements would be the Director™, Scanning Director™, FreeSwitch™, GEWA, and X10 Activehome Computer Interface Kit. Of these minimally wasteful systems, only GEWA claims to fulfill all of Mr. Rawlings' required control options.

### **Mobility Considerations**

Mr. Russels' lifestyle, as is the lifestyle of other people with disabilities on campus, is not sedentary. Mobility introduces the problem of having to obtain the input switch to perform a momentary task, and then remove the switch from the tray to attend to something else. For example, if a light in the main dormitory room must be turned off, the sequence of events is very cumbersome. In the time it takes for an assistant or friend to deliver the switch to the user, the lamp itself could as easily be activated by the assistant. Therefore, ECSs which support only a wire link to the base control unit do not provide much advantage. In cases where an extended activity such as watching television is involved, the problem is not as severe.

Wireless RF and IR transmitter switches, and voice recognition, are clearly much less awkward for the mobile user. For example, Mr. Rawlings could potentially have a transmitter permanently fixed to his tray. With voice recognition, Mr. Rawlings would just need to approach the microphone to access the ECS.

However, voice recognition is not essential for Mr. Rawlings, as he could use an ability switch or large button. Voice recognition adds significant cost to an ECS due to the internal processing involved, and elimination of this input option leaves less expensive ECS choices for Mr. Rawlings.

### **RATINGS**

Table 3 shows ratings of the 14 systems based on the data gathered and summarized. The following criteria are used:

- Input portability
- Feedback portability
- Number of missing functions
- Number of wasted functions
- Cost for base system, but for easy comparison must include:
  - Accessible telephone (built in or extra)
  - regular light switches
  - fluorescent light switches
  - large appliance or lamp modules

To further characterize the systems, a separate column for the system organization is presented. Computer based systems or systems with a central control box/transmitter

were identified. Some of these systems also showed significant segmentation of input processing and control hardware, where the user was required to use different input devices or modalities. Examples would be the Scanning Director™, which uses a switch for TV and X10 control, and requires a separate voice or switch controlled telephone. GEWA is considered segmented because the base IR transmitter shares duties with receivers that control complex functions, such as the INFRA-LINK telephone.

## Systems Rated

| System                     | <u>Computer Based<br/>Central Unit,<br/>Segmented<br/>Control</u> | Input<br>Portability | Feedback<br>Portability | # Missing<br>Options:<br>Standard /<br>+ Phone,<br>X10 Blinds<br>and Temp. | # Wasted<br>Functions<br>(Excluding<br>extra X10<br>options) | Cost w/<br>Phone<br>&<br>8 Light +<br>Appliance<br>Modules |
|----------------------------|---|----------------------|-------------------------|--|--|--|
| DEUCE                      | Central Base Unit   | √√                   | √√                      | 1 / 0  | 4  | √√   |
| Director™                  | Central Base Unit<br>Segmented                                    | √<br>×               | √                       | 5 / 4  | 0  | √√√<br>♣   |
| FreeSwitch™                | Segmented   | √                    | ♣                       | 5 / 2  | 0  | √√√<br>♣   |
| GEWA                       | Central Base Unit<br>Segmented                                    | √√                   | ♣                       | 1 / 0  | 5  | √<br>♣   |
| HECS                       | Central Base Unit   | √                    | √                       | 3 / 1  | 2  | √  |
| Imperium®<br>200H          | Central Base Unit   | √√                   | √√                      | 3 / 1  | 3  | √  |
| PROXi                      | Computer  | √√√                  | √                       | 3 / 1  | 2  | √√   |
| Scanning<br>Director™      | Central Base Unit<br>Segmented                                    | √                    | √<br>♣                  | 4 / 1  | 0  | √√<br>♣  |
| Simplicity™<br>Series 5, 6 | Central Base Unit   | √√√                  | √√√                     | 2 / 0  | 5  | √  |
| Simplicity™<br>Series 7,7M | Central Base Unit   | √                    | √√√                     | 2 / 0  | 5  | √  |
| Simplicity™<br>Four-In-One | Central Base Unit   | √√√                  | √√√                     | 2 / 0  | 5  | √<br>♣   |
| X10 Ah. Cp.<br>Interf. Kit | Computer<br>Segmented   | √<br>×               | √                       | 4 / 1  | 0  | √√√<br>♥   |

**Table 3:** The fourteen units are rated with Mr. Rawlings requirements in mind.

Key:

- × Not easily useable by Mr. Rawlings
- ♣ No feedback required in some cases. Selection via directional remote control or tactile contact. Visual contact made with selected appliance.
- ♦ Most expensive system.
- ♥ Least expensive system.
- ♣ Peripherals (X10, telephone, or INFRA-LINK receivers) added significant cost.

| Rank | Relative meaning | For Input:                                    | For Feedback:               | For Cost:   |
|------|------------------|---|-----------------------------|-------------|
| √    | Satisfactory     | Direct wired input, most assistance required. | Fixed visual display.       | >\$3000     |
| √√   | Better           | Wireless input, some space on tray required.  | Audio tone / extra display. | \$1001-3000 |
| √√√  | Best             | Voice input, tray not affected.               | Voice feedback.             | <\$1000     |

## **Conclusions (Part I): Recommended ECS Design Modifications**

The systems that were examined in this study are all able to sufficiently meet most of Mr. Rawlings most important needs. However, there were many areas where modifications could reduce the cost or increase the convenience of the systems.

When the ECSs are compared to Mr. Rawlings' requests, requirements, and environment, we see some inefficiencies. There are many instances of over-functionality in the 14 ECSs that were examined in this study. Perhaps work should be done on developing scaled down versions of highly complete ECSs. These products would not include hospital and home security features; subsequently, they would be more cost effective. This cost savings could be passed on to the client, and would widen a market consisting of dormitory room residents across the nation. These residents would be more interested in an ECS scaled specifically for a small, communal environment than one intended for an entire household or a hospital room.

It was seen in the examination of fourteen ECSs that a few instances of control segmentation showed a potential for cost savings. With segmentation, subsystems with varying levels of complexity are used independently. This is different than completely relying on a main unit or personal computer to interpret many types of input, communicate with many different peripheral devices, and store user profiles. The problem of generating integrated circuitry or computer software which can simultaneously support switch inputs, voice inputs, communication with an X10 TW523 (Rye, 1995) transceiver, communication with a universal IR remote control, telephone phone control, hospital device control, etc., is difficult. Segmentation provides simplification of the environmental control problem.

Mobility is an important factor in the evaluation of the ECSs. Mr. Rawlings wheelchair mobility makes the use of hardwired switch inputs and stationary displays somewhat inconvenient. While many ECSs answer this need by creating portable transmitters or using voice recognition, all manufacturers should look into providing some kind of portability of the input mechanism. Additionally, in systems that use visual feedback from a display to let the user know what devices are being activated, some research on portable displays should be conducted. For example, a centralized control box could be outfitted with a radio frequency transmitter to relay information to a receiver on the user's wheelchair.

Finally, ECSs need to adequately address the problem of temperature control. None of the selected systems suggested or mentioned a method to access the thermostat. While a temperature setback controller can be used to activate the air-conditioning or heat, precise and stable control over the temperature may not be possible in some systems. Precise thermostat replacements are available from X10, but some of them require too many of the device codes to be used. Subsequently, certain ECSs might not be able to control X10 appliance modules and an X10 thermostat simultaneously.

## **Part II:**

### **Segmentation and Specialization, a Balanced and Optimized Solution**

In the first part of this study, we looked at the problem of environmental control for people with disabilities in the Texas A&M University dormitories. The client, Russel Rawlings, aided the study by identifying accessibility options for appliances that he felt were most important. Many inefficiencies were identified, primarily caused by wasted features and over-centralization.

The motivation for this study was the high cost of ECSs. There is a potential need for environmental control in communal college settings, yet the \$2000-\$5000 price tag for some of the ECSs is probably an obstacle for many families with children in college. The problem of cost can be attacked by removing unwanted functionality from the centralized control systems.

Studies at the University of Michigan have proposed that some cost savings and increased flexibility can be achieved by a computer-based ECS (Simpson, Ashlock, & Levine, 1996). Their research shows that computers are more readily funded, are flexible to many input modalities via modification of software, are able to provide better feedback (via display or speech) about the properties of the environment, can be updated in software, and can be used in combination with existing commercial peripheral controllers such as X10 modules. UMECHS (University of Michigan Environmental Control System) is such an ECS which was created by the Rehabilitation Engineering Program there.

However, we would like to look at other alternatives besides computer based ECSs for three reasons:

- They are already available on the market.
- They might be somewhat inconvenient due to the fixed computer screen feedback.
- Some people do not own computers.

The final reason is perhaps the greatest motivation. Although Mr. Rawlings owns a personal computer, we would like to investigate other alternatives because they might result in a more global benefit. Computer controlled ECSs do not offer much advantage when the cost of an entire PC is added to the price tag of the ECS software and hardware.

### **Advantages and Disadvantages of Segmentation**

This portion of the study looks at some conceptual ideas for "middle-of-the-road" strategies which consider making some sacrifices in convenience in order to make gains in functional efficiency. Segmentation of environmental control may be able to attain this goal.

It was seen in the examination of fourteen ECSs that a few instances of control segmentation showed potential for cost savings. Segmentation means that, rather than completely rely on a CPU to interpret many types of input, communicate with many different peripheral devices, and store user profiles, subsystems with varying levels of complexity are used independently. This simplifies the problem of generating integrated circuitry or computer software which can simultaneously support different switch inputs and voice inputs, communicate with an X10 TW523 (Rye, 1995) transceiver, communicate with a universal IR remote control, provide phone control, etc.

Unfortunately, segmentation of a system may mandate that two or more different methods of input are used. Rather than have a single switch or voice recognition system that can access all functions, there may be a switch for one set of similar environmental controls and a switch for another set of controls. This introduces some inconvenience, and some assistance for changing out of switches may be required.

Two alternative systems are briefly described. One system, conceived by Karl Greb, (a Texas A&M University student studying Computer Engineering), uses a digital signal processor as a CPU specialized for X10 communication. Another system, which was constructed in the course of this study, uses simple IR receivers that operate relays in the same fashion as many X10 modules.

## **Alternative Systems Concepts**

### **DSP BASED X10 CONTROL**

Communication with X10 lamp modules, light switches, appliance modules, blinds controllers, and thermostat setback controllers can provide Mr. Rawlings with the ability to access all controls over everything he desires except for the telephone, television, VCR, and stereo. Development of a CPU that is specifically designed use X10 communication standards over the power wiring in the dormitory room can be achieved with relative ease using a digital signal processor.

#### **The TMX320F240 Processor Core**

Work was done with Karl Greb to attempt a design of an X10 controller subsystem for use with other environmental control devices. Karl Greb proposed that a Texas Instruments DSP model TMX320F240 be used for such a task. The TMX320F240, which costs only about \$35, possesses both random access memory and a permanent memory which could be rewritten. This memory would be used to store programs and incoming data used in math processing. The DSP would then emit the proper digital X10 command codes at a frequency of one bit per zero crossing of the 60 Hz wall outlet voltage. These bits would be sent as modulated 120 kHz bursts to the power outlet. The 120 kHz frequency would be generated by a hardwired oscillator circuit which is powered by the DSP.

### **Output Method: X10 Protocols**

In order for the zero crossing to be detected, a full wave rectifier with the appropriate voltage step down circuitry is used. The analog to digital module onboard the DSP then detects voltage fluctuations between approximately 0 and 5 volts as opposed to 0 and 120 volts. Near a voltage of zero, the DSP is authorized to give the next bit in the queue if a command is being sent. The information sent conveys the identity of the sender (or house code), the intended X10 recipient (device code), and the command code ("turn on," or "turn off").

### **Input Method: IR Signals**

For input, the DSP based system would use a standard IR receiver with a 38 kHz centered band-pass response. This "Infrared detector module" is a standard part (#276-137) distributed by Radioshack® and costs \$3.60. The detector is an active-low logic device: it outputs 5 volts when no signal is present and 0 volts when a 38 kHz IR signal is present.

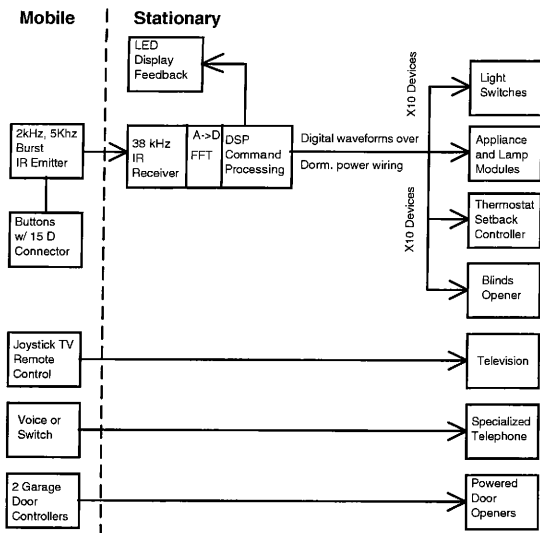
The DSP would respond to two commands, "cycle to next device" and "toggle device." Feedback would consist of a simple set of LEDs labeled with the different devices that are available. Incoming 2 kHz or 5 kHz bursts of the 38 kHz IR signal would differentiate the commands. A Fast Fourier Transformation algorithm would be run by the DSP to detect these two frequencies in the IR detector.

A simple, push button IR transmitter with two different buttons would deliver the commands. The transmitter, small and portable, would be placed on Mr. Rawlings' wheelchair, with the buttons being placed on the tray. Control over the DSP based X10 subsystem could easily be achieved at a distance up to 6 or 7 feet.

### **Integration with other Subsystems**

Using other subsystems dedicated to their own modes of input and control, almost all of Mr. Rawlings' needs can be met. This DSP based X10 controller could be used in conjunction with Mr. Rawlings' existing door openers, an Assis-TECH RC100 or RC200 telephone, and a Joystick Controlled Television Remote Control (Appendix A). Figure 5 shows a block diagram of this system.

## Integrated System with DSP based X10 Controller



**Figure 5:** Environmental control system with segmentation of input and control. X10 control subsystem uses a Texas Instruments DSP.

### Disadvantages

Drawbacks of the segmentation are that the Joystick TV Remote Control might get in the way of the IR transmitter switch and the two garage door openers on the tray. It's presence would not be necessary outside of the room or during times when tray clutter would not be desired. So, some assistance would be required to remove or obtain the Joystick TV Remote Control. If the RC100 (switch controlled telephone) were used, the same difficulty applies.

Also, the current Joystick TV Remote Control would be able to control only 1 IR appliance at a time. Although other control options are more important, the lack of more



IR appliances represents a weakness when this alternative ECS is compared to many traditional ECSs.

### **Advantages**

However, there is a gain in cost effectiveness. Mr. Greb estimates that once the initial development was completed, the labor and material cost to assemble a DSP X10 controller would total \$290. With 100% markup of the device, purchase of an RC200 telephone, and construction of a Joystick TV Remote Control, the entire base system totals a little over \$1000 (excluding X10 modules). This price is thousands less than the existing ECSs which integrate all desired functions into a single control box.

### **Realization of the Design**

Although Karl Greb attempted this design (with our help) for his senior design project, there was not enough time to complete all of the assembly code and successfully burn the programs into the flash memory on the DSP. However, ECS manufacturers and interested engineers should seriously consider this design as a feasible, lower end alternative to the traditional ECS. The cost reduction potential is introduced by using an inexpensive CPU for X10 control. Other inexpensive and specialized elements can then be added to expand control in a complete system capable of sufficiently addressing the most essential functions in a small environment such as the dormitory room.

### **INFRARED POINT AND CLICK SYSTEM**

It was noted that the most essential environmental control options, temperature, lighting, and appliance power, have only "on" and "off" states. X10 modules employ these states by interrupting the power to the appliances which are plugged into them. The X10 product line has been built around the concept of using a central transmitter to control many peripheral X10 units, and this is the basis for the convenience of home automation. Unfortunately, the traditional ECS reliance on X10 peripheral control mandates usage of some sort of centralized system. As we have seen, it is this combination of X10 communication and other forms of communication which increase the complexity of the problem and contribute to the cost of ECSs.

A centralized system mandates that the user selects devices by list cycling or verbal command. However, the mobility and dexterity that Mr. Rawlings demonstrates introduces a simplification. It is possible to take advantage of his wheelchair mobility as the method of selection, much the same way people with full mobility physically activate an appliance. With a simple, switch activated remote control mounted on Mr. Rawlings' chair, he can use direction and proximity to control IR receptive relay circuits. The basic components of this "Point and Click" system were ultimately designed and built in the process of this study.

## **Output Method: The IR Receivers**

The system uses a network of simple IR activated power relays. These relays perform the same functions as the X10 appliance and lamp modules. This provides control over lamps, on/off type appliances, and the thermostat setback module.

Circuitry in the receiver stores the current state of the device. When a strong IR signal at the proper frequency is detected, the state is toggled. Toggling of the state also toggles a 5 volt relay whose contacts are rated for an amount of power sufficient for the appliance. The relay bridges a connection between the wall outlet and the appliance which is plugged into the receiver.

The IR detector module is so sensitive that operation of a TV remote control can set off a receiver as far away as 15 feet. So, optical obstruction of the receiver with a 0.5 mm thick piece of opaque material (such as aluminum or plastic) is employed to reduce the sensitivity. When a remote control comes within 3 feet of the receiver, it becomes effective at toggling the relay. Direction has an effect on selection as well, as the optical signal strength greatly attenuates with increasing angle. So, both proximity and direction are employed to perform selection and activation simultaneously.

## **Input Method: IR Signal**

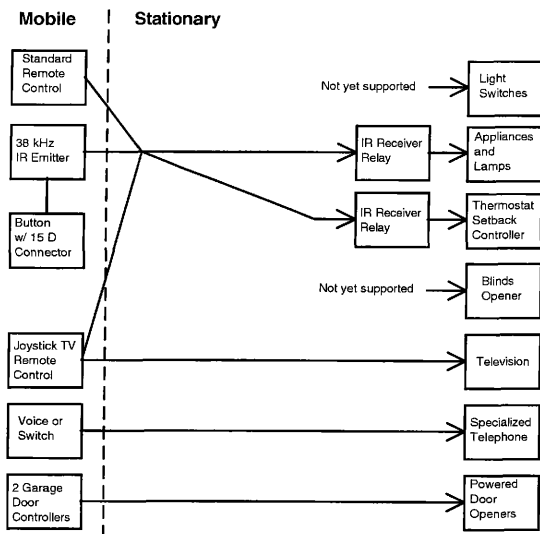
A J-K latch IC stores the state of the receiver. A slow clock running at about 0.5 Hz is implemented with an oscillator circuit. If a positive result is seen by the latch on an upward clock movement, the latch toggles its current state (0 or 5 volts). The receiver uses the Radioshack IR detector module, part #276-137, and an inverter IC in series to give this toggling signal upon the presence of 38 kHz IR modulation.

Either a standard remote control, the Joystick TV Remote Control, or a simple IR transmitter can be used to activate the receiver. A simple IR transmitter, designed with Mr. Russels' abilities in mind, was built for use with the receivers. It features a 15 pin connector similar to those found on many joysticks. A lever style switch was built for the transmitter; pulling on the lever results in an emission of a 38 kHz square wave IR signal.

## **Integration with other Subsystems**

As in the system which used the DSP based X10 Controller, integration of the Infrared Point and Click subsystem with other subsystems can provide most functions requested by Mr. Rawlings. Although the Infrared Point and Click system currently provides no definite solution for light switches, lighting can still be controlled through standard lamps in the room. Temperature control is also available. Use of the Joystick TV Remote Control, existing garage door openers, and an RC100 or RC200 telephone provide the other functions requested by Mr. Rawlings. Figure 6 shows the block diagram of this integrated system.

## Integrated System with IR Point and Click Control



**Figure 6:** Environmental control system which integrates IR receptive relays in similar fashion to X10 modules.

One function that cannot yet be implemented is control over the blinds. A modified receiver must be designed for this control option. The state output of the latch can be tied to reversed relays which alternately supply power in one direction or another to a motor in the presence of an incoming signal. Latch output and IR detector output would be ANDed together with an AND IC at the connection to each separate relay magnet. The motor, with appropriate interface and gearing, could then be used to open or close the blinds.

Also, no solution has been implemented for light switch control. However, the basic receiver could be used to interrupt the light switch circuit. Otherwise, lighting can be controlled through the on/off toggling of lamps plugged into the receivers.

### **Disadvantages**

This system suffers from the same drawbacks as the DSP based system. If a switch controlled telephone is used, some assistance is required to obtain the switch. Also, while depression of almost any button on a standard TV remote control can activate a receiver, use of the remote control on the receiver could inadvertently affect the television. (A suggested button is the "down volume" button, as the effect on the TV is not as irritating.) A final disadvantage is that blinds control, also the least important function on Mr. Rawlings' list, is not currently implemented.

The receivers' designs do not include an onboard power supply which can harness the needed current from the incoming AC power. While a simple power supply could be implemented, the current design uses a 6V DC power supply which must occupy it's own outlet. If there were a shortage of outlets, power strips would need to be purchased.

### **Advantages**

This system has virtually eliminated complex centralized control at a tremendous savings in cost. However, each receiver's materials cost is about \$25, approximately twice that of most X10 lamp or appliance modules. In a small room with relatively few devices to be controlled, this added cost is not significant in comparison to the cost of an ECS base unit. Integration of an onboard power supply would reduce the cost of the receiver down to about the same level of the X10 modules.

With 8 receivers, 8 power supplies, two extra power strips, the Joystick TV Remote Control, and the RC200 phone, the materials cost of this system is only \$650, with the telephone occupying the majority of that cost (\$400). If these receivers were hypothetically marketed, the profit markup would probably be offset by wholesale availability of parts and the ease of manufacturing printed circuit boards.

### **Realization of the Design**

A transmitter and receiver pair were constructed to demonstrate the feasibility of the design. A more detailed explanation of the design is presented in the next main section of this study. Circuit diagrams and pertinent component characteristics are included.

### **Part III:**

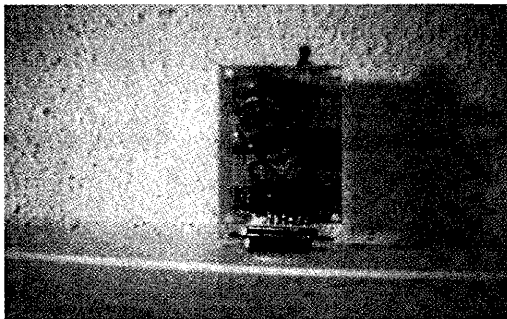
## **An Example Subsystem Design for Use with Other Subsystems**

The design of an infrared link to on or off state devices/appliances was generated. These binary state appliances easily control the most basic of functions in environmental control: lighting and temperature. IR receptive power relays respond to non-coded signals from IR transmitters such as television remote controls. Since the receivers do not need to recognize codes, their designs are relatively simple.

### **Switch Activated IR Transmitter**

Although a television remote control could be used to activate the receivers described in this environmental control subsystem, a switch activated IR transmitter was designed to give Mr. Rawlings a better physical interface. The transmitter was developed in conjunction with Karl Greb's *DSP based X10 Controller* as an input device for that subsystem, so it contains extra functionality not necessary for this Infrared Point and Click subsystem. Instead of the minimum 1 command, 3 commands are available from this transmitter; all commands have the same effect in the Infrared Point and Click subsystem. Figure 7 shows a picture of the transmitter circuit.

#### **3 Command IR Transmitter**



**Figure 7:** Picture of IR transmitter internals. Outer casing not shown. The perforated board measures about 1.5 x 2.5 inches.

Figure 8 shows the schematic for this device. Resistance values are given in ohms and capacitance values are given in farads.

### 3 Command IR Transmitter Schematic

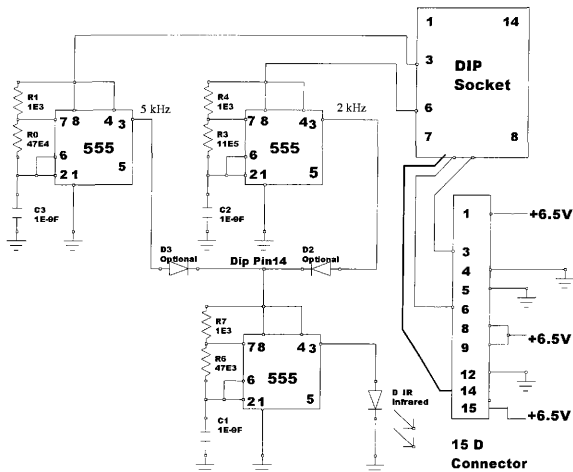


Figure 8: Schematic of a simple, 3 command IR transmitter.

### OSCILLATING COMPONENTS

This circuit uses 555 TTL ICs (timer chips). In combination with the correct resistor and capacitor values, the three 555 timers create square wave oscillator circuits at the desired frequencies. The frequency of oscillation for any timer can be determined by this relationship (Lancaster, 1997):

$$f = 1.44 / [(R_1 + 2R_2) * C]$$

$R_1$  is connected to pins 7 and 8 on the 555 timer IC.  $R_2$  is connected to pins 7 and 2.  $C$  is connected to pin 2 and the ground. Making  $R_2$  large in comparison to  $R_1$  makes the duty cycle very even.  $R_1$  should not be smaller than 1 k $\Omega$ . (Lancaster, 1997) When this circuit was built in the laboratory, some adjustment of the resistors was required. This was due

to small differences in the capacitance values and the timer circuits' frequency response effects on each other.

### **Issuing Commands**

One 555 timer drives the infrared emitting diode. Its fundamental frequency must be 38 kHz for the best response in the IR receivers. It can be activated directly with pin 14, resulting in a positive output from an IR detector module in a receiver. Activation of pin 14 issues one command.

The other two 555 timers oscillate at approximately 2 kHz and 5 kHz. These timers drive the main 38 kHz timer, creating 2 and 5 kHz bursts of the 38 kHz signal. In an IR detector module, this produces square waves at 2 and 5 kHz, corresponding to two more commands.

### **SWITCHES**

The control switch plugs into the 15 D connector. Power is bridged by the switches through the transmitter's 6.5 volt battery pack (4 AA batteries), to pins 3, 6, and 14. Simple push-buttons may be used as the switches, but there are many options which could potentially be used. As long as the switch uses a 15 D connector and has the appropriate pin connections as given in this design, it can be used to activate the transmitter. Figure 9 shows the switch built in this study.

## Example Switch



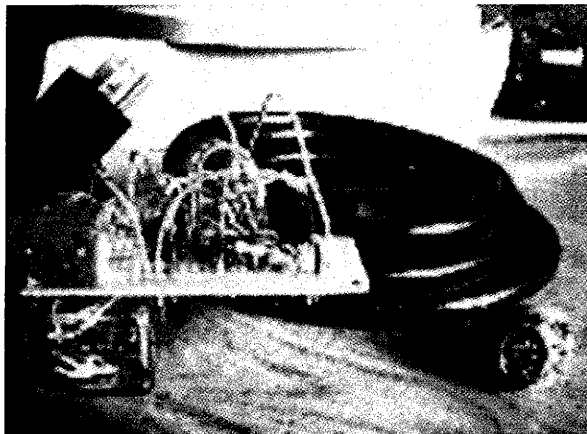
**Figure 9:** Internals of a switch built for Mr. Rawlings. Outer casings not shown.

## IR Receptive Relay Circuit

A infrared receiver which can toggle power to an appliance was developed. The receiver is intended to take the place of an X10 appliance or lamp module, providing environmental control over lamps, thermostat setback controllers, etc. The design is based on a JK latch which stores the state (on or off) of the relay. The relay is driven indirectly by this latch. A slow clock output allows the receiver to constantly look for a strong signal in the IR detector module. When one is present, the latch toggles its state upon an upward clock swing. Figure 10 shows a picture of the internal circuit, power cord, and relay of the constructed receiver.



## IR Receiver

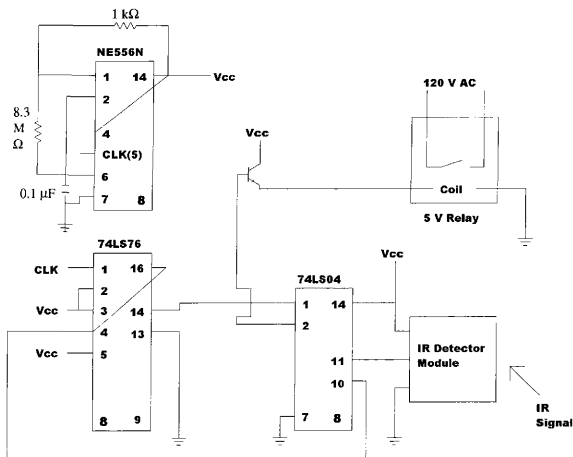


**Figure 10:** IR receiver with power relay (lower left). IR detector module has a grill through which light can pass (middle left). Relay interrupts power to the M/M adapter (top left). Appliances plug into that adapter, which then plugs into a wall outlet. Class ring shows scale (lower right).

Clocked latching effectively serves as a simple filter. Tests in the laboratory showed that periodic bursts of high frequency noise would erupt from the IR detector. A preliminary design, which used a D-latch and the IR detector input as the clock, was too sensitive to this noise; ghost commands would be picked up. The JK latch and clock assure that toggling can only occur when a strong, DC signal is present. Reduction of the detector sensitivity with physical obstruction aids in the stability of the receiver.

Figure 11 shows an electrical wiring schematic for the IR receiver. The entire system is designed to run between 5 and 6.5 volts, optimally. This voltage is provided by a DC power source that plugs into a jack on the receiver. Note that the output from the IR detector module must be run through an inverter (74LS04), since it is originally active low. As in the IR transmitter circuit, a 555 timer IC is used to create an oscillating square wave--this serves as the clock. In this specific case, an NE556N (dual) timer IC was used because it was readily available. Either IC will work, as only one timer is necessary.

## IR Receiver Schematic



**Figure 11:** Electrical wiring diagram of a toggling relay circuit which responds to IR input.

## THE IR DETECTOR

The "Infrared Detector Module" is a standard component available from Radioshack®, and is part #276-137. It measures approximately 1.5 x 1.5 x 1 cm. Circuitry in the detector has a band-pass response of 38 kHz. The IR detector can recognize signals from the Switch Activated IR Transmitter, or any standard remote control. The output of the detector is connected to pin 11 of the inverter (74LS04), since it is active low and a high output is required to toggle the JK latch.

A window on the detector allows light to pass into the module. It was necessary to reduce the sensitivity of the IR detector module, as regular operation of a television set could trip the circuit. The window was obstructed with a thin piece of aluminum to greatly reduce the sensitivity.

## STATE MEMORY

The latch (74LS76), receives a clock from the NE555N timer. If there is a DC signal at pin 4 of the latch during an upward clock transition, the state of the latch output (pin 14) will change. The state output of the latch, pin 14, is used to activate/deactivate the magnetic switch in the relay. However, the signal was first passed through the hex inverter to buffer the signal. It was found that current loading on the 74LS76 output could result in instability in the state.

## RELAY CONTROL

A typical NPN transistor is used as a simple current driver; the TTL components are not able to provide enough current for some of the larger relays. The relay interrupts the power to one prong in a 3-prong adapter. The controlled appliance plugs into the adapter, which is then plugged into the wall. The receiver is connected to this adapter by a cable; it must be in the same area as the appliance.

Care should be taken in choosing the relay that is appropriate for the amount of power that the appliances will need. Large PC relays have contacts rated to the currents that some small lamps, alarm clocks, etc., will need to operate. More robust contacts will be needed to power larger appliances, such as televisions, refrigerators, microwave, etc. The smaller relays will always be much cheaper, so choosing the appropriate relay is important in optimizing the cost of the receiver.

## Evaluation

Originally, this environmental control subsystem was to be tested by Mr. Rawlings. However, he did not return for the Spring semester, and it was decided that the devices would be built anyway. While preliminary tests show that the IR transmitter and receiver pair work nicely, an integrated system with many different receivers is not yet completed.

Clearly, complete verification of this environmental control subsystem would require long term usage under real conditions in the dormitory. The proximity at which receivers can be placed and still be individually activated must be determined. Clearly, some strategic placement and spacing of receivers is necessary to reduce cross activation of receivers. Also, the long term stability of the circuits needs to be determined. The receivers must maintain their state indefinitely until a good signal is seen. Whether or not they can maintain their state over a period of several hours or days remains to be seen. Preliminary testing of the receiver built in this study indicates that no false positives occur over course of 2 hours.

While there was insufficient time to accomplish field testing, we have demonstrated that a simple, inexpensive design is possible. No menu system or sequential scanning is necessary; the user can simply maneuver himself near a receiver to activate it. There are no codes or advanced processing involved in this subsystem, and therefore no CPU. This

eliminates an expensive component of the ECS. If the Infrared Point and Click system is used in conjunction with other subsystems, environmental control can be achieved at a relatively low cost. The Infrared Point and Click transmitter and receivers use very inexpensive components, with the exception of the relays (which can range from a few dollars to forty dollars).

By itself, the Infrared Point and Click system can provide simple and quick access to lighting and temperature (through lamps and a setback controller). For some users, these may be the most important environmental controls, as in the case of Mr. Rawlings. The development of simple products such as the Infrared Point and Click system can benefit people with disabilities who do not have the budget to purchase a comprehensive ECS with a \$4000 price tag. The development of simple environmental control devices can open up many new possibilities.

## Conclusions

There is potentially a large market of students with disabilities who desire environmental control in their dormitory rooms. Available ECSs, in general, do not efficiently meet their needs in their small, communal living space.

In the examination of 14 Environmental Control Systems, centralized control with supreme functionality dominates the designs. However, these products are very expensive, and may not be affordable for many people with disabilities.

System segmentation is one way that the cost of ECSs could be reduced. Some segmented products on the market, but not all, have a lower price than purely centralized systems. The drawback is that segmentation can incur certain inconveniences, such as discontinuity of the input mechanism.

Some segmented systems have been outlined here. Both the DSP based X10 Controller and the Infrared Point and Click subsystems show great cost savings potential when they are integrated with other environmental control devices, such as the accessible telephone.

The Infrared Point and Click design shows the greatest cost savings potential. The low cost is achieved by taking advantage of simplifying factors. The wheelchair mobility of the user becomes the selection mechanism, therefore eliminating any need for a centralized control unit. Unfortunately, this reliance on mobility may exclude some potential users. For them, traditional ECSs may in fact be much better at solving their control problems.

Hopefully, more research will be conducted on reducing the cost of environmental control products and generating designs of varying degrees of sophistication. If lower cost ECSs become available, there is the possibility that they could even be offered as standard accommodations in educational institutions and in the private sector. At least, they will become more affordable and more available.

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## Appendix A

### X10 HOME AUTOMATION PRODUCTS

Environmental control systems often employ X10 compatible modules to physically control appliances. Most of these modules plug into wall outlets, and the controlled appliances plug into the modules. Pictures of an example lamp module/appliance module, wall outlet module, light switch module, and thermostat setback controller are shown below. One difference between a lamp module and an appliance module is that the appliance module accepts 3 prong, grounded plugs. Also, the appliance module handles more current than the lamp module, and does not have the ability to "dim" the appliance (Home Automation Systems, Inc., 1995).

#### Example X10 Receivers

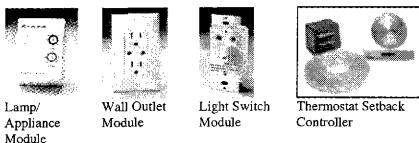


Figure 12: Various X10 receivers.

Source: "Products." 1997. < <http://www.x10.com/products/products.htm> > (April 1998).

### X10 COMMUNICATION

Most X10 products communicate over the power wiring in the household. An X10 transmitter uses a proprietary X10 protocol which is recognized by the X10 receivers. On an isolated power circuit, there may be up to 16 transmitters. Each transmitter can send commands to 16 separate receivers. Therefore, on any isolated circuit, the maximum number of X10 receivers that can be controlled is 256.

"1" bits are represented as 1 millisecond, 120 kHz bursts, and the absence of the bursts are "0" bits (Rye, 1995). At each zero crossing of the three phase power system, the bits are transmitted. The information that is sent is this sequence of codes (Rye, 1995):

- |                           |        |
|---------------------------|--------|
| • start                   | 4 bits |
| • house (transmitter ID#) | 4 bits |
| • number (receiver ID#)   | 5 bits |

The sequence is repeated for redundancy. This sequence primes the receiver that belongs to the transmitter. A similar sequence then issues the specific command (e.g. "turn on"). In the command sequence, the function code takes the place of the number code.



## **JOYSTICK TV REMOTE CONTROL**

The Joystick TV Remote Control is a device modification of an existing programmable remote control. The main function buttons (power, volume, channel) on a One For All™ remote control are connected via ribbon cable to a digital joystick. Some users with physical disabilities can use this improved joystick interface, whereas the buttons on the regular remote control may be too small to manipulate. Designs for this modification are available from Dr. William Hyman, Biomedical Engineering Department Head at Texas A&M University. Approximately \$50 in materials are used in the construction of the device.